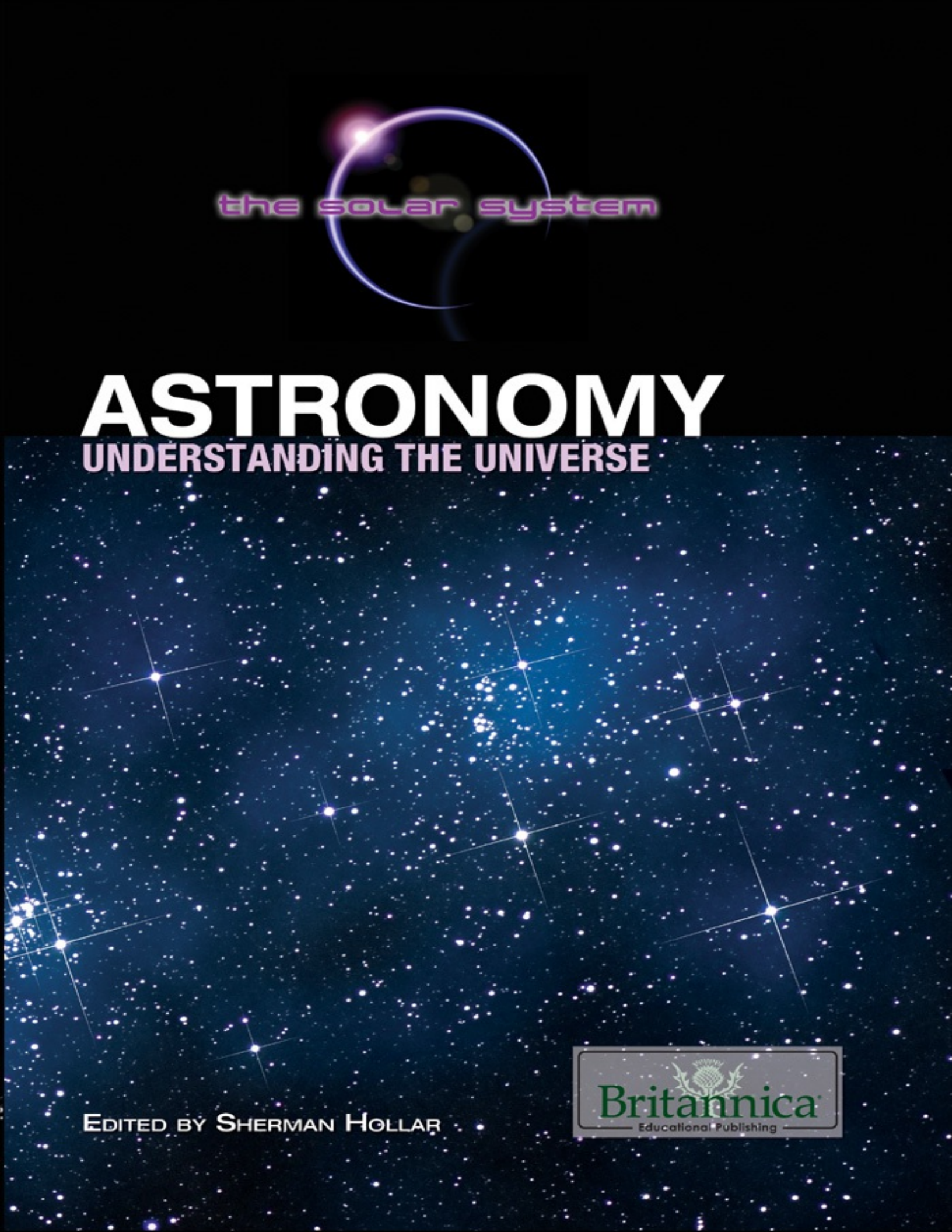
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ASTRONOMY
UNDERSTANDING THE UNIVERSE
EDITED BY SHERMAN HOLLAR
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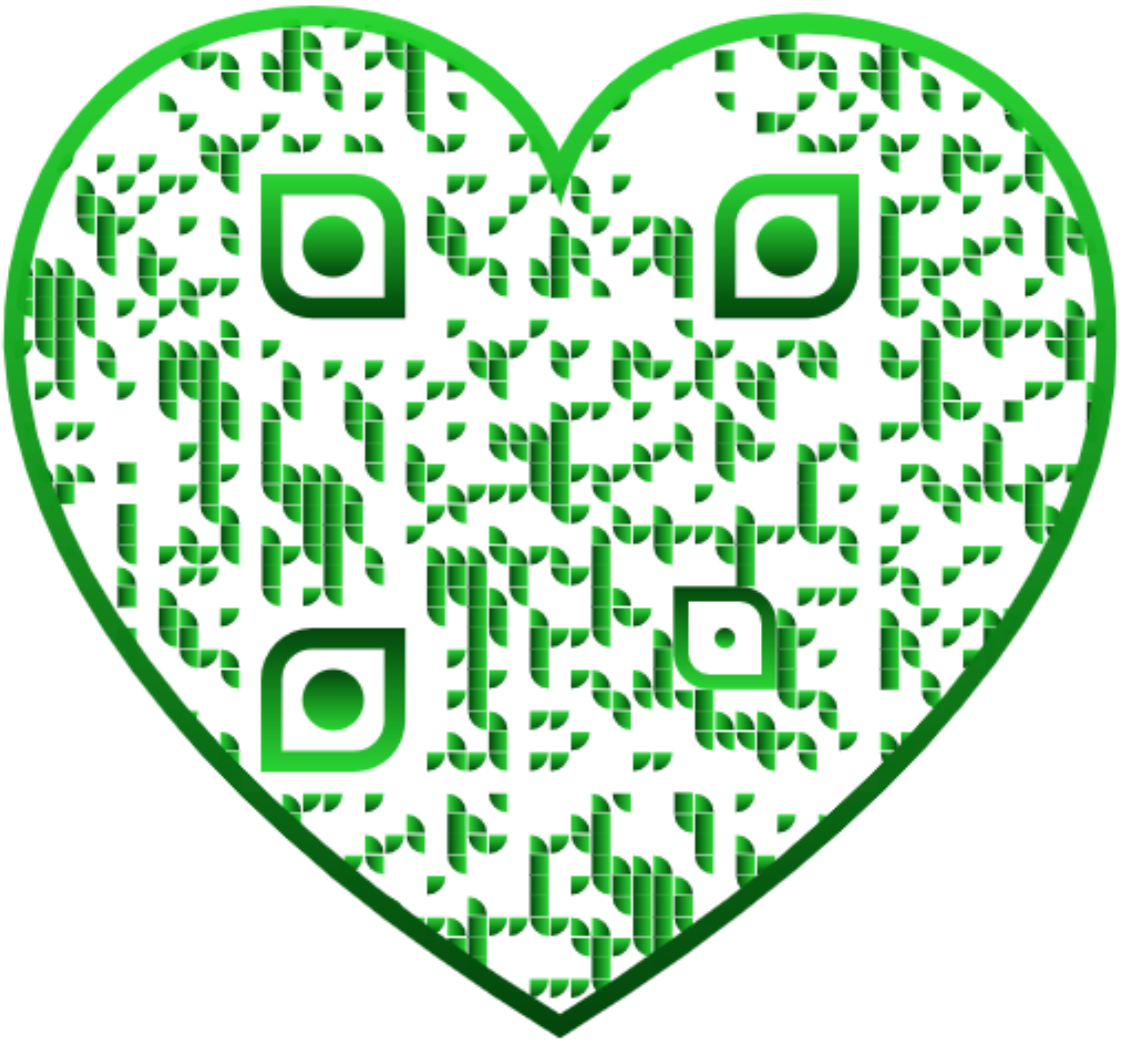

the solar system

ASTRONOMY
UNDERSTANDING THE UNIVERSE

Edited by Sherman Hollar

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On the cover, page 3: An open cluster of stars in the northern constellation of Perseus.
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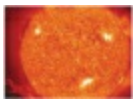

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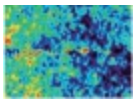

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introduction

Millions of lucky people in Africa and Asia had the opportunity to witness an unusual celestial event on January 15, 2010. Using special dark glasses, pinhole cameras, and other devices so that they would not be blinded by the Sun, they saw a rare annular solar eclipse. This kind of eclipse takes place when the Sun is closest to Earth and the Moon is farthest away, so the Moon does not completely cover the Sun. This means that at the peak phase of the eclipse the rim of the Sun is visible all around the disk of the Moon. The peak phase of the January 15 eclipse lasted 11 minutes and 8 seconds. Such a duration for an annular solar eclipse will not be exceeded until the year 3043. The subject of eclipses is just one of the many fascinating topics you will learn more about in this volume.

Early Egyptians and Chinese used their eyes to study the annual patterns of the sky carefully enough to make accurate calendars. During the 2nd century AD, the Egyptian astronomer Ptolemy formulated his geocentric (Earth-centered) model of the universe now known as the Ptolemaic system. It was not until the 1500s that the Polish astronomer Nicolaus Copernicus determined that Ptolemy's notion that the Sun revolves around Earth was

invalid—instead, he concluded that Earth and the other planets actually orbit around the Sun.

Observers watch the January 15, 2010, annular solar eclipse at the central stadium in Thiruvananthapuram, Kerala, South India. **EyesWideOpen/Getty Images**

But there was no way to prove Copernicus' idea until the invention of the telescope. This revolutionary new piece of technology allowed Italian astronomer Galileo Galilei in the early 1600s to carefully record the movement of different heavenly bodies, including four moons which he observed revolving around Jupiter. Galileo's findings paved the way for the confirmation of Copernicus' theory. Over time, telescopes have been getting larger and more powerful. Now there are even telescopes in space. NASA's Kepler space telescope recently revealed a rocky planet, named Kepler-10b, that astronomers believe to be the smallest planet ever discovered outside our solar system.

In the 20th century, scientists deepened their understanding not only of astronomy but also cosmology, the study of the universe and its laws. Along with technology, scientists use mathematics and physics to make discoveries. Albert Einstein revolutionized cosmology in 1905 with his special theory of relativity, which stated that space and time could be seen as parts of a deeper structure, space-time, and that mass and energy are really the same thing. Scientists later developed the big bang theory. According to this theory, the universe started some 13 billion years ago with a sudden expansion of matter and antimatter. Many scientific tests have confirmed the validity of this theory.

In this book, you will learn about important advances that astronomers have made through time. But you will also learn that astronomy is one of the few sciences in which amateurs can play a significant role. You do not need your own Kepler telescope or a Ph.D. in physics to make a significant contribution. With the proper tools—including knowledge and a sharp eye—even an amateur can make an important discovery. In 1995 two amateur astronomers, Alan Hale and Thomas Bopp, working independently of each other, spotted a comet beyond the orbit of Jupiter. Comet Hale-Bopp, as it came to be known, reached perihelion (the closest distance to the Sun) on April 1, 1997, without ever coming very close to Earth. It was, however, spectacularly visible to the naked eye and became perhaps the most widely witnessed comet of the 20th century.

Chapter 1
THE VISIBLE SKY

Since the beginnings of humankind people have gazed at the heavens. Before the dawn of history someone noticed that certain celestial bodies moved in orderly and predictable paths, and astronomy—an ancient science—was born. Yet some of science's newest discoveries have been made in this same field, which includes the study of all matter outside Earth's atmosphere. From simple observations of the motions of the Sun and the stars as they pass

across the sky, to advanced theories of the exotic states of matter in collapsed stars, astronomy has spanned the ages.

For centuries astronomers concentrated on learning about the motions of heavenly bodies. They saw the Sun rise in the east and set in the west. In the night sky they saw tiny points of light. Most of these lights—the stars—seemed to stay in the same place in relation to one another, as if they were all fastened to a huge black globe surrounding Earth. Other lights, however, seemed to travel, going from group to group of stationary stars. They named these moving points planets, which means “wanderers” in Greek.

***New stars are forming from the hot gas and dust of the Orion nebula, a major “stellar nursery” only some 1,500 light-years from Earth. Our sun probably formed in a similar environment. More than 500 separate images were combined to create this mosaic*. NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team**

Ancient astronomers thought that the positions of celestial bodies revealed what was going to happen on Earth—wars, births, deaths, and good fortune or bad. This system of belief is called astrology. Most scientists no longer believe in astrology, but they have found that some ancient astrologers were good at observing the motions and positions of stars and planets.

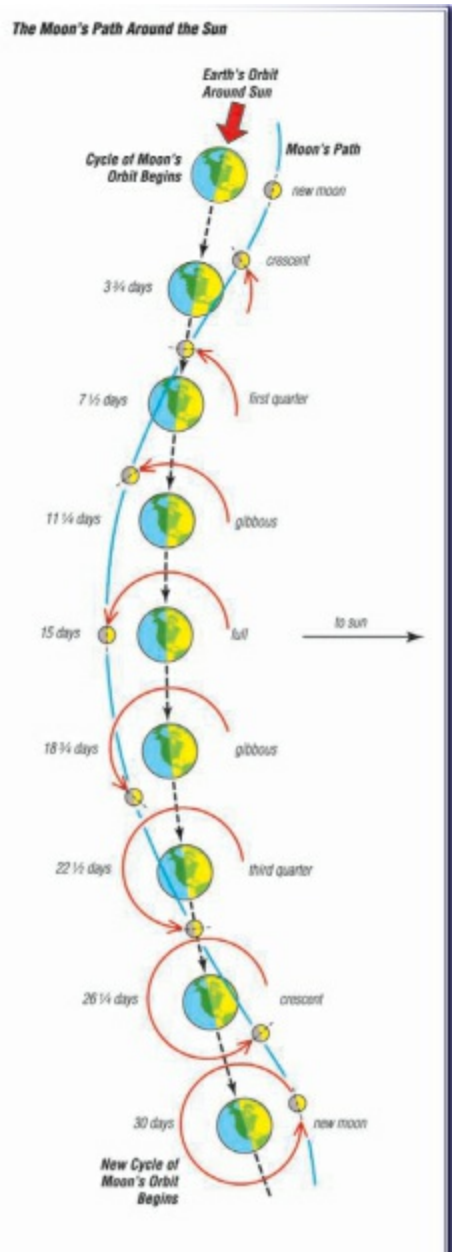
When people today look at the sky without a telescope or other modern instrument, they see basically the same things the ancient astronomers saw. During a clear day one can see the Sun and sometimes a faint Moon. On a clear night one can see stars and usually the Moon. Sometimes a star may seem to be in different positions from night to night: it is really a planet, one of the "wanderers" of the ancients. The planets all circle the Sun, just as Earth does. They are visible from Earth because sunlight bounces off them. The stars are much farther away. Most stars are like the Sun—large, hot, and bright. They shine from their own energy.

A broad strip of dim light is also visible across the night sky. It is a clustering of faint stars known as the Milky Way. The Milky Way is part of the Milky Way galaxy—an enormous cluster of stars, of which the Sun is only one member out of more than 100 billion stars. Other galaxies exist far beyond the Milky Way.

EARTH IN SPACE

The apparent westward motion of the Sun, the Moon, and the stars is not real. They seem to move around Earth, but this apparent motion is actually caused by Earth's movement. Earth rotates eastward, completing one rotation each day. This may be hard to believe at first, because when one thinks of motion one usually also thinks of the vibrations of moving cars or trains. But Earth moves freely in space, without rubbing against anything, so it does not vibrate. It is this gentle rotation, uninhibited by significant friction, that makes the Sun, the Moon, and the stars appear to be rising and setting.

Planet Earth rises above the moon's horizon in an unprecedented view captured in December 1968 by Apollo 8 astronauts as their orbit carried them clear of the far side of the moon. **NASA**



As the moon revolves in an almost circular path around Earth, Earth moves in a similar path around the sun. Both motions combine to give the moon a wavy orbit. **Encyclopædia Britannica, Inc.**

Earth is accompanied by the Moon, which moves around the planet at a distance of about 30 Earth diameters. At the same time, Earth moves around the Sun. Every year Earth completes one revolution around the Sun. This

motion, along with the tilt of Earth's rotation axis (relative to the axis of its revolution around the Sun), accounts for the changes in the seasons. When the northern half of Earth is tipped toward the Sun, the Northern Hemisphere experiences summer and the Southern Hemisphere, which is tipped away from the Sun, experiences winter. When Earth has moved to the other side of the Sun, six months later, the seasons are reversed because the Southern Hemisphere is then tipped toward the Sun and the Northern Hemisphere is tipped away from the Sun.

The Moon does not always look the same from Earth. Sometimes it looks round, sometimes like a thin, curved sliver. These apparent changes are called the phases of the Moon. They occur because the Moon shines only when the Sun's light bounces off its surface. This means that only the side of the Moon that faces the Sun is bright. When the Moon is between Earth and the Sun, the light side of the Moon faces away from Earth. This is called the new moon, and it is not visible from Earth. When the Moon is on the other side of Earth from the Sun, its entire light side faces Earth. This is called the full moon. Halfway between the new and full moons, in locations on either side of Earth, are the first quarter and the last quarter (which look like half disks as viewed from Earth).

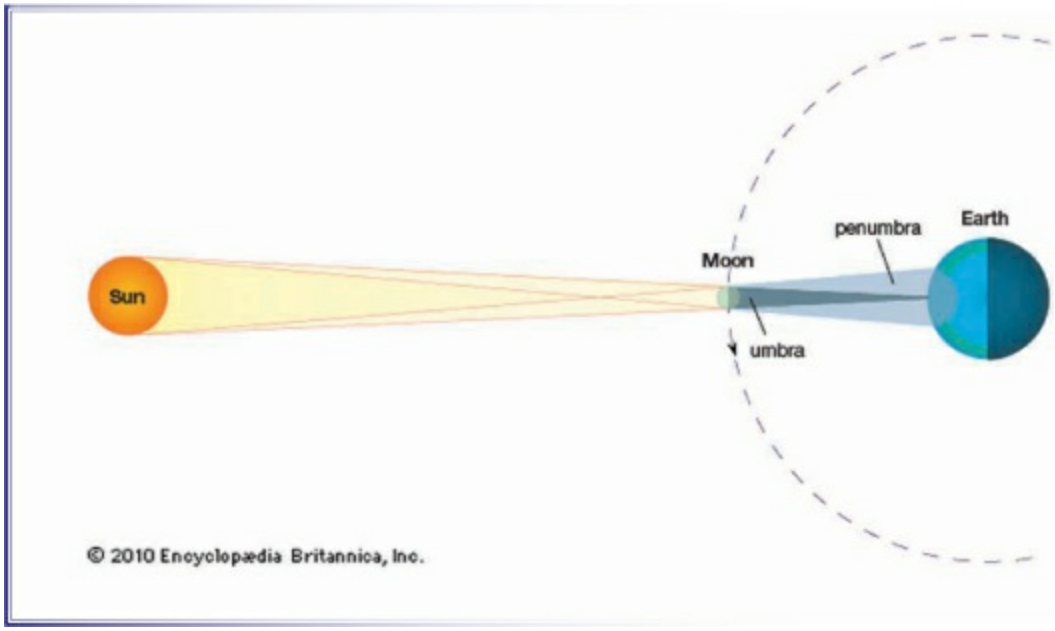
ECLIPSES

In ancient times people often were terrified when the Sun or the Moon seemed to disappear completely when normally it would be visible. They did not understand what caused these eclipses. Eventually, astronomers reasoned that lunar eclipses (when a previously full moon at least partly disappears from the night sky) are the result of Earth passing between the Moon and the Sun. Earth thus casts a shadow on the Moon. Similarly, solar eclipses (when the Sun partly or totally disappears from the daytime sky) occur when the Moon passes between Earth and the Sun. The Moon thus blocks the Sun's light temporarily.

Eclipses occur irregularly because the plane of the Moon's orbit around Earth is slightly different from the plane of Earth's orbit around the Sun. The two planes intersect at an angle of about 5 degrees. This means that the Moon is usually slightly above or below the line between Earth and the Sun, so neither Earth nor the Moon throws a shadow on the other. Eclipses can occur only when the Moon lies at one of the two points where the planes intersect.

If this were not so, there would be lunar eclipses with every full moon and solar eclipses with every new moon.

When the Moon does pass directly into Earth's shadow, a circular darkening gradually advances across the Moon's face, totally covering it within about an hour. Usually the Moon remains dimly visible as sunlight passes through and is refracted (bent) by Earth's atmosphere, thus reaching the otherwise darkened lunar surface. After another hour or two, the Moon has left the shadow and again appears full. Interestingly, during the partial phases of a lunar eclipse, Earth's shadow is easily seen to be circular. This indicated to at least some early astronomers that Earth is approximately spherical.



***In the successive phases of a solar eclipse, the dark disk of the moon gradually moves across the disk of the sun from west* (right) *to east* (left). Copyright Encyclopædia Britannica, Inc.; rendering for this edition by Rosen Educational Services**

When the Moon's shadow falls on Earth, a much more dramatic spectacle occurs. The shadow consists of two parts—the umbra and the penumbra. In the penumbra, the Moon blocks only part of the Sun, and on Earth many

people may not notice anything unusual. The umbra, however, is the cone-shaped region in which the Sun's light is totally blocked. When the tip of this shadow reaches Earth, the Moon's disk appears big enough in Earth's sky to cover the Sun. This patch of darkness is rarely more than 150 miles (240 kilometers) wide. It races across Earth at over 1,000 miles (1,600 kilometers) per hour as the Moon moves. Those in its path see the Sun completely disappear from the sky and are enveloped in darkness almost as deep as night for up to about 7 minutes.

During totality the Sun's corona, or outer atmosphere, can be seen surrounding the black silhouette of the Moon's disk. The corona is only about as bright as a full moon and is normally blotted out by the bright daytime sky. An eclipse provides a rare opportunity to see the corona.

Sometimes the umbra fails to reach Earth's surface, meaning that the Moon is too far from Earth to appear big enough to totally cover the Sun. This leaves a thin but bright ring of sunlight at mid-eclipse. Such eclipses are called annular. They occur a bit more frequently than total eclipses do.

Only the total phase of a solar eclipse is safe to view, as looking at even a small part of the Sun can cause permanent eye damage. Various filters and other methods exist to allow safe viewing of partial phases, but even these should be used with care.

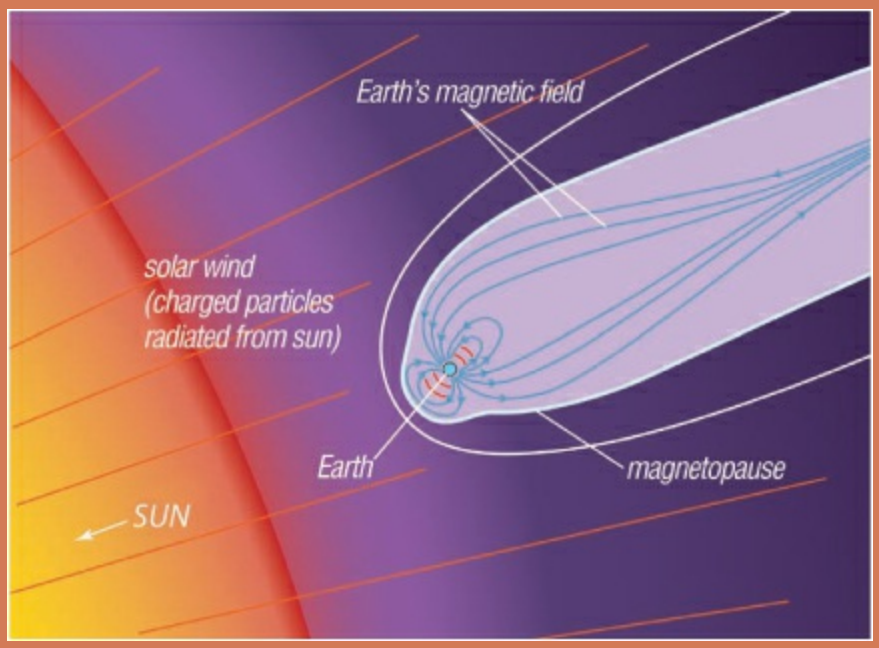
ROCKS FROM OUTER SPACE

Sometimes one can see a flash of light streak across the night sky and disappear. Although this is commonly called a shooting star, real stars do not shoot through the sky any more than the Sun does. Many small chunks of stone, metal, or other materials orbit the Sun. Sometimes they enter Earth's atmosphere, and the friction generated by their great speed causes them to burn up. The fragments may either vaporize before traveling far or actually hit the ground.

THE NORTHERN AND SOUTHERN LIGHTS

People who are relatively near the North or South Pole may see one of nature's most lavish displays—the aurora borealis (northern lights) or the aurora australis (southern lights). High in the skies

over Earth's magnetic poles, electrically charged particles from the Sun swarm down into Earth's atmosphere. As these particles collide with air molecules, auroras—brilliant sheets, streamers, or beams of colored lights—are given off at heights ranging from about 50 to 200 miles (80 to 320 kilometers) up in Earth's atmosphere.



***The Sun gives off a continuous stream of charged particles. When this stream, called the solar wind, reaches Earth, it deforms Earth's magnetic field. Some of the particles spiral down near the magnetic poles, where they cause auroras*. Encyclopædia Britannica, Inc.**

The streams of charged particles are known as the solar wind. The Sun continually sends a flow of these particles out into space. During periods when the Sun is unusually active—that is, when it has large sunspots on its surface—the solar wind is particularly strong. Huge swarms of the particles then reach Earth's atmosphere, causing large and brilliant auroras.

These objects have different names depending on their location. One that

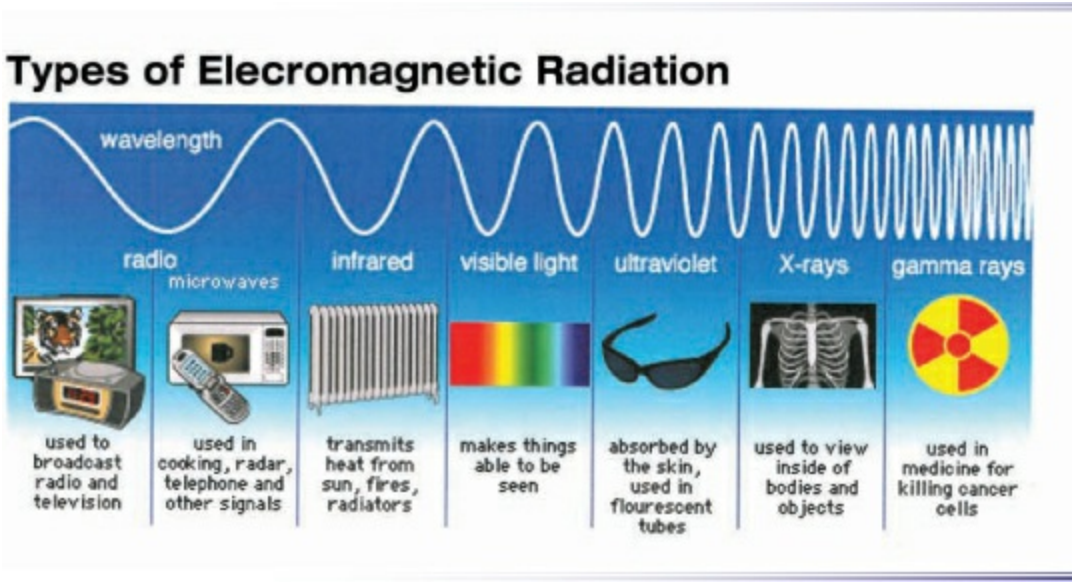
is beyond Earth's atmosphere is called a meteoroid. A meteoroid that enters Earth's atmosphere is called a meteor. A meteor that actually lands on Earth's surface is called a meteorite.

Meteorites, which are sturdy enough to reach the ground, apparently are pieces of asteroids. Asteroids are huge rocks that orbit the Sun. Most meteors that burn up in the atmosphere are tiny dustlike particles, the remains of disintegrated comets. Comets are flimsy objects made mostly of frozen water, frozen gases, and some gritty material. They also orbit the Sun.

Sometimes a swarm of meteoroids enters Earth's atmosphere, causing a meteor shower, with tens or hundreds of "shooting stars" flashing across the sky in less than an hour. Virtually all of these meteors burn up in the upper atmosphere. A significant amount of dust and ash from meteors settles on Earth each day. The Leonid meteors caused the greatest meteor showers on record, in 1833 and 1966. These meteors appear every November, with especially dazzling displays about every 33 years. The Leonid meteors are so named because their motion relative to Earth makes them appear to come from the direction of the constellation Leo.

Chapter 2
TOOLS AND TECHNIQUES OF ASTRONOMY

Astronomers are at a distinct disadvantage compared with practitioners of other sciences; with few exceptions, they cannot experiment on the objects they study. Virtually all the information available is in the form of electromagnetic radiation (such as light) arriving from distant objects. Fortunately, this radiation contains an amazing number of clues to the nature of the objects emitting it.



***Radio waves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays are all types of electromagnetic radiation. Radio waves have the longest wavelength, and gamma rays have the shortest wavelength*. Encyclopædia Britannica, Inc.**

Electromagnetic radiation travels in the form of waves, or oscillating electric and magnetic fields. In its interaction with matter, however, it is best understood as consisting of particles, called photons. These waves occur in a vast variety of frequencies and wavelengths. In order of increasing frequency (decreasing wavelength) these parts of the electromagnetic spectrum are called radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays. As particles, radio wave photons carry the least amount of energy and gamma rays the most.

TELESCOPES

Naturally, the first part of the spectrum to be studied with instruments was visible light. Telescopes, first used for astronomy by Italian astronomer Galileo Galilei in 1609, use lenses or mirrors to form images of distant objects. These images can be viewed directly or captured using film or electronic devices. Telescopes gather more light than the naked eye and

magnify the image, allowing finer details to be seen. Even though early telescopes were crude by today's standards, they almost immediately allowed discoveries such as the Moon's craters, Jupiter's moons, Saturn's rings, Venus' phases, sunspots, and thousands of previously unseen stars.

In the 20th century new technologies allowed the development of telescopes capable of detecting electromagnetic radiation all the way across the spectrum. Many objects emit most of their "light" at frequencies well outside the visible range. Even objects that do emit visible light often betray much more information when studied at other wavelengths.

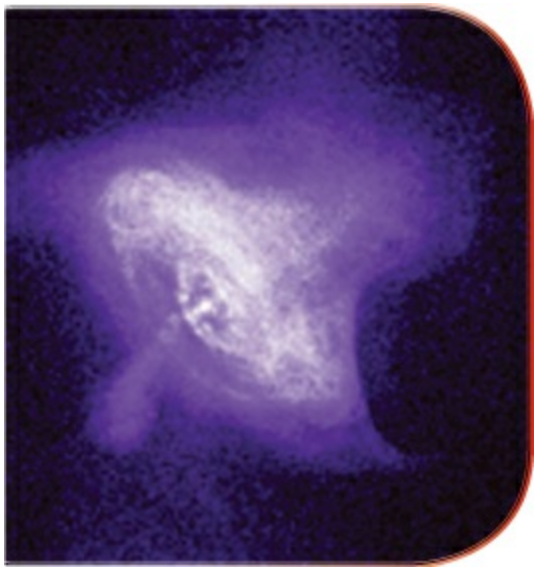
By the 1990s optical (visible light) telescopes reached enormous size and power, a good example being the Keck telescopes on top of Mauna Kea in Hawaii. These two telescopes have collecting mirrors 33 feet (10 meters) in diameter, allowing detection of objects millions of times fainter than can be seen with the naked eye, with detail about a thousand times finer. Actually, astronomers seldom look through such telescopes directly. Instead, they use cameras to capture images photographically or newer, more sensitive detectors to capture images electronically. Most work is now done with electronic detectors, including charge-coupled devices (CCDs).

***The Hubble Space Telescope appears in a photograph taken from the space shuttle* Discovery *on December 21, 1999*.**
NASA

Since the 1940s radio telescopes have made great contributions. The largest single antenna, with a dish diameter of 1,000 feet (300 meters), is the Arecibo instrument in Puerto Rico. Huge arrays of multiple telescopes, such as the Very Large Array (VLA) in New Mexico, allow highly detailed imaging using radio waves, which otherwise yield rather "blurry" images. The largest is the Very Long Baseline Array (VLBA), consisting of 10 dishes scattered over an area thousands of miles across the United States. Data from these instruments are correlated using a technique called interferometry. The level of detail that can then be seen in radio-emitting objects (such as the centers of distant galaxies) is equivalent to discerning a dime at a distance of a few thousand miles.

A tremendous advance has been the placement of astronomical instruments in space. Telescopes and other instruments aboard unmanned spacecraft have explored all the Sun's planets at close range. At least as important, though, have been large telescopes placed in Earth orbit, above the obscuring and blurring effects of Earth's atmosphere.

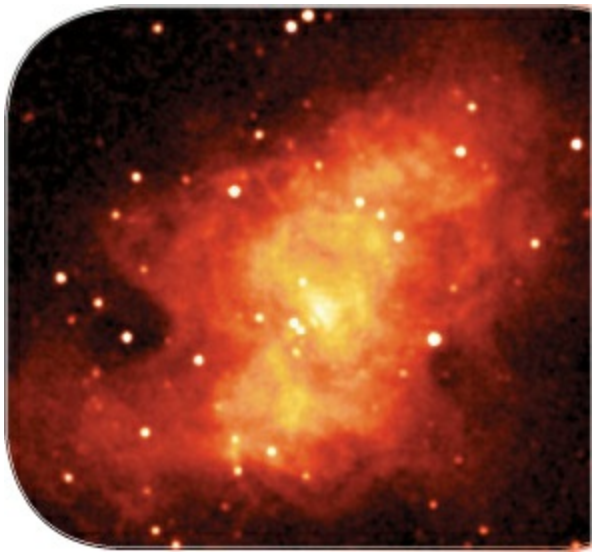
The best known of these telescopes is NASA's Hubble Space Telescope, which was launched in 1990 into an orbit 380 miles (610 kilometers) above Earth's surface. It initially returned disappointing images, owing to a mistake in the grinding of its 94.5-inch (2.4-meter) primary mirror. In 1993 space shuttle astronauts installed corrective optics, and ever since it has returned magnificent data. While Hubble is smaller than many groundbased telescopes, the lack of air to distort the images has generally allowed it better views than can be had from the ground, leading to many discoveries. Interestingly, a technology called adaptive optics now allows many ground-based telescopes to rival Hubble's level of detail, by removing much of the blurring effect of the atmosphere.



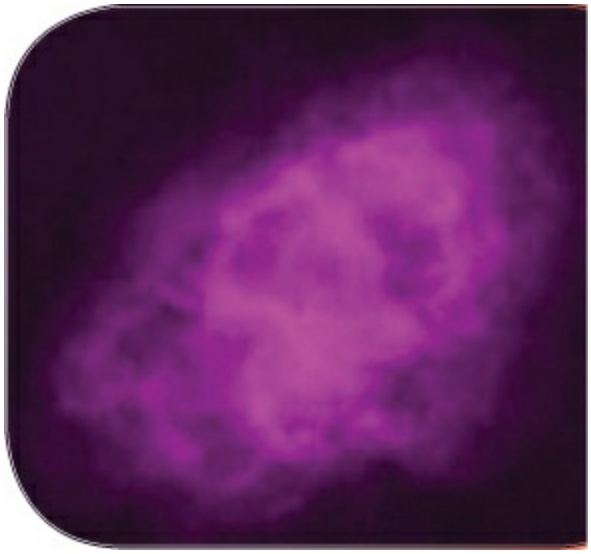
Images of the Crab nebula captured at different wavelengths of electromagnetic radiation reveal different features. The nebula is the remains of a star that Chinese astronomers saw explode in AD 1054. At its center is a pulsar, or the star's very dense collapsed core that spins rapidly while beaming out radiation. The Crab nebula is still undergoing violent expansion. This X-ray image from the Chandra X-Ray Observatory reveals high-energy particles that the pulsar seems to have blasted outward, in rings from the center and in jets perpendicular to the rings. Over time, the particles move farther outward and lose energy to radiation. The cloud of lower-energy gas and dust surrounding the pulsar can be seen in images taken at longer wavelengths. (The images are not to scale. The area of the nebula shown in visible light is actually 60 percent larger than the area shown in X-rays. The area shown in radio waves is about 20 percent larger than that in visible light.)
NASA/MSFC

Less well known than Hubble but perhaps just as important are several other space telescopes that specialize in other parts of the spectrum. NASA's Compton Gamma Ray Observatory (whose mission lasted from 1991 to 2000) and Chandra X-ray Observatory (launched in 1999) have sent back a flood of data about objects such as neutron stars and black holes. These

objects produce high-energy radiation that is largely blocked by Earth's atmosphere. NASA's Spitzer Space Telescope (launched in 2003) detects a wide range of infrared radiation, which is emitted by cooler objects, including interstellar clouds of gas and dust, where stars and planets form.



The Crab nebula appears in an infrared image. **2MASS/UMass/IPAC- Caltech/NASA/NSF**



The Crab nebula appears in a radio image. **VLA/NRAO**

SPECTROSCOPY: WHAT LIGHT TELLS ASTRONOMERS

Stars give off a whole range of electromagnetic radiation. The kind of radiation is related to the temperature of the star: the higher the temperature of the star, the more energy it gives off and the more this energy is concentrated in high-frequency radiation. An instrument called a spectrograph can separate radiation into the different frequencies. The array of frequencies makes up the spectrum of the star.

The color of a star is also an indication of its temperature. Red light has less energy than blue light. A reddish star must have a large amount of its energy in red light. A white or bluish star has a larger amount of higher-energy blue light, so it must be hotter than the reddish star.

Stars have bright or dark lines in their spectra. These bright or dark lines are narrow regions of extra-high emission or absorption of electromagnetic radiation. The presence of a certain chemical, such as hydrogen or calcium, in the star causes a particular set of lines in the star's spectrum. Since most of the lines found in stellar spectra have been identified with specific chemicals, astronomers can learn from a star's spectrum what chemicals it contains.

COMPUTER MODELING: WORLDS INSIDE A MACHINE

While astronomers mostly cannot experiment with real astronomical objects in the laboratory, they can write computer programs to employ the laws of physics to simulate the structure and behavior of the actual objects. These models are never perfect, since both computing power and detailed knowledge of the structure and composition of the objects of interest are limited. In some situations, there are even uncertainties in the laws themselves. Nonetheless, these models can be adjusted until they closely match observable features and behavior of real objects.

Among the many types of astronomical phenomena that can be modeled are the evolution of stars, planetary systems, galaxies, and even the universe itself. Models of stars have successfully simulated their observed properties and supply predictions of what happens to them as they age. Other models have shown how planets can form from rotating clouds of gas and dust. Models of the early universe

allow astronomers to study how large-scale structures such as galaxies developed as gravity accentuated tiny differences in the universe's density. As computers and modeling techniques have improved, this has become an ever more important tool of astronomy.

Spectrum lines are useful in another way, too. When an observer sees radiation coming from a source, such as a star, the frequency of the radiation is affected by the observer's motion toward or away from the source. This is called the Doppler effect. If the observer and the star are moving away from each other, the observer detects a shift to lower frequencies. If the star and the observer are approaching each other, the shift is to higher frequencies.

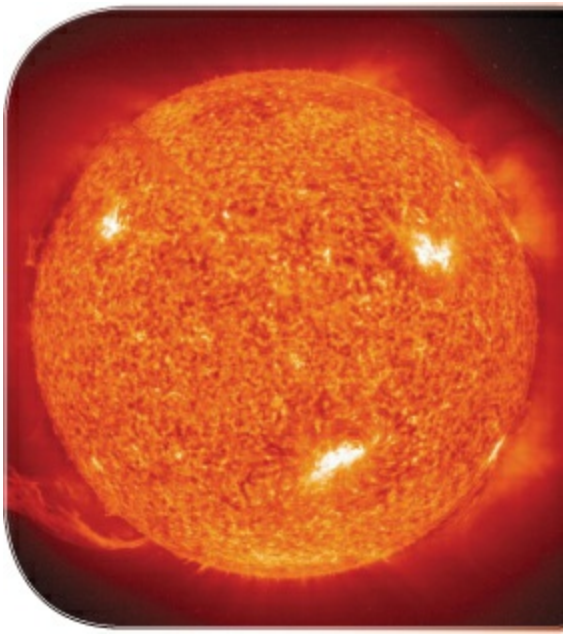
A star's color indicates its surface temperature. The Hubble Space Telescope captured this dazzling image of a star cloud in the constellation Sagittarius. Most of these stars are fairly faint and orange or red, which is how the sun would appear. The blue and green stars are hotter than the sun, while the bright-red stars are red giants, which are much cooler stars near the end of their lives. The sun will eventually become a red giant. **The Hubble Heritage Team (AURA/STScI/NASA)**

Astronomers know the normal spectrum-line frequencies for many chemicals. By comparing these known frequencies with those of the same set of lines in a star’s spectrum, astronomers can tell how fast the star is moving toward or away from Earth.

Chapter 3
THE SOLAR SYSTEM

The solar system consists of the Sun plus all the objects that orbit it. With more than 99 percent of the solar system's total mass and a diameter more than 100 times that of Earth and 10 times that of Jupiter, the Sun is quite naturally the center of the system. The spectrum, brightness, mass, size, and age of the Sun and of nearby stars indicate that the Sun is a typical star. Like most stars, the Sun produces energy by thermonuclear processes that take

place at its core. This energy maintains the conditions needed for life on Earth.



At the center of the solar system is the Sun, which produces an enormous amount of energy. This image was taken in extreme ultraviolet light by the Earth-orbiting Solar and Heliospheric Observatory (SOHO) satellite. Nearly white areas are the hottest, while deep-red regions are the coolest. A massive prominence can be seen erupting at lower left. **NASA**

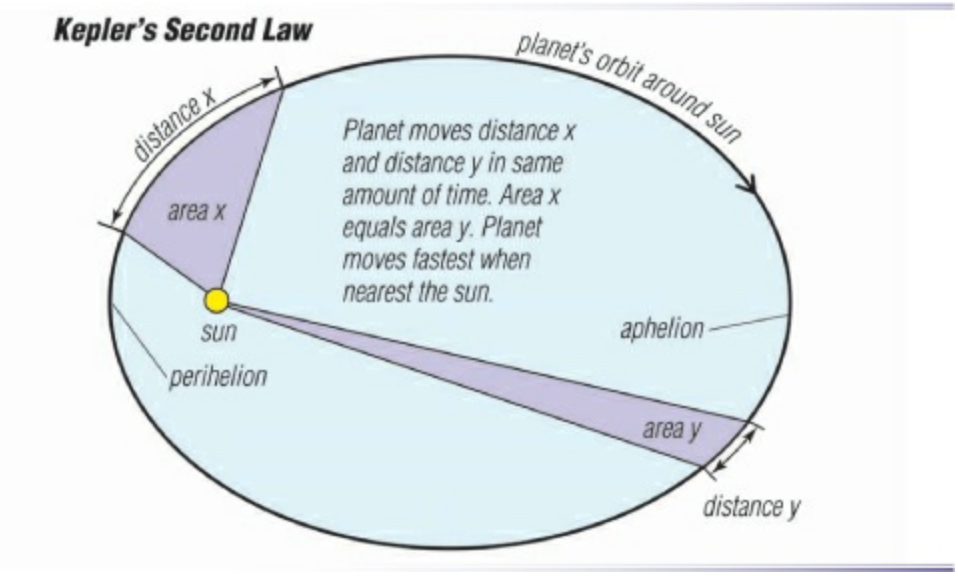
As has been mentioned above, Earth is not the only body to circle the Sun. Many chunks of matter, some much larger than Earth and some microscopic, are caught in the Sun's gravitational field. Eight of the largest of these chunks are called planets. Earth is the third planet from the Sun. The smaller chunks of matter include dwarf planets, natural satellites (moons), asteroids, comets, meteoroids, and the molecules of interplanetary gases.

KEPLER'S LAWS OF PLANETARY MOTION

In the early 1600s astronomers were beginning to accept the idea that Earth and the planets revolve around the Sun, rather than that the Sun and the

planets revolve around Earth. Astronomers were still unable, however, to describe the motions of the planets as accurately as they could measure them. The German astronomer Johannes Kepler was finally able to describe planetary motions using three mathematical expressions, which came to be known as Kepler's laws of planetary motion.

In carefully studying Mars, Kepler found that its orbit is not circular, as had been assumed. Rather, the orbits of the planets are elliptical, with the Sun at one of two fixed points in the ellipse called foci. Also, as a planet travels around the Sun, its speed is greater when it is closer to the Sun. An imaginary line drawn from the moving planet to the Sun would sweep out equal areas in equal time intervals. Finally, Kepler found a mathematical relationship between a planet's average distance from the Sun and its orbital period (the time it takes to complete an orbit). Specifically, he found that the squares of the planets' orbital periods are proportional to the cubes of their average distances from the Sun.


Kepler's Second Law
planet's orbit around sun
distance x
area x
Planet moves distance x and distance y in same amount of time. Area x equals area y. Planet moves fastest when nearest the sun.
sun
perihelion
aphelion
area y
distance y

Kepler's second law of planetary motion describes the speed of a planet traveling in an elliptical orbit around the Sun. It states that a line between the sun and the planet sweeps equal areas in equal times. Thus, the speed of the planet increases as it nears the Sun and decreases as it recedes from the Sun. **Encyclopædia Britannica, Inc.**

To find these laws, Kepler had to effectively make a scale drawing of the solar system. He did this using extremely accurate observations collected by his former employer, the Danish astronomer Tycho Brahe. Kepler used a relative distance scale in which the average distance from Earth to the Sun was called one astronomical unit.

Kepler did not have a particularly accurate value for the astronomical unit. To help find this distance, later astronomers were able to use methods such as parallax. In astronomy, a parallax is the difference in direction of a celestial object as seen by an observer from two widely separated points. The two positions of the observer and the position of the object form a triangle; if the base line between the two observing points is known and the direction of the object as seen from each has been measured, the apex angle (the parallax) and the distance of the object from the observer can be found simply. Even more advanced methods have determined that Earth's average distance from the Sun is in fact 92,955,808 miles (149,597,870 kilometers).

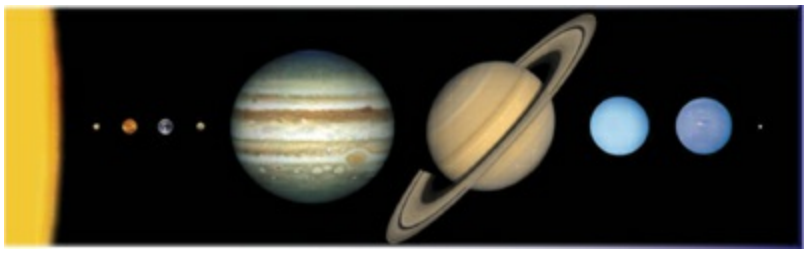
NEWTON'S LAW OF UNIVERSAL GRAVITATION

Kepler's laws described the positions and motions of the planets with great accuracy, but they did not explain what caused the planets to follow those paths. If the planets were not acted on by some force, scientists reasoned, they would simply continue to move in a straight line past the Sun and out toward the stars. Some force must be attracting them to the Sun.

The English scientist Isaac Newton calculated that in order for Kepler's laws to have the form they do, this force must grow weaker with increasing distance from the Sun, in a particular way called an inverse square law. He also realized that the Moon's curved path around Earth was a type of weak acceleration toward Earth. He calculated this acceleration to be much less than that of an apple falling from a tree. In comparing these accelerations, he found their difference to be described by the same inverse square law that described the force the Sun exerted on the planets. Even the orbits of the other planets' moons could be similarly explained. Newton concluded that all masses in the universe attract each other with this universal force, which he called gravitation.

THE PLANETS

Up to the 18th century people knew of seven bodies, besides Earth, that moved against the background of the fixed stars. These were the Sun, the Moon, and the five planets that are easily visible to the unaided eye: Mercury, Venus, Mars, Jupiter, and Saturn. Then, in 1781, William Herschel, a German-born English organist and amateur astronomer, discovered a new planet, which became known as Uranus.



***A montage shows the eight planets of the solar system plus Pluto, with the images placed right next to each other and scaled to show their approximate sizes relative to one another. (The distances between them are not to scale.) The yellow segment at left represents the Sun, to scale. The planets, from left to right, are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. Pluto, at right, was classified as a planet from the time of its discovery in 1930 until 2006, when the International Astronomical Union made it the prototype of a new category of celestial objects, dwarf planets*. NASA/Lunar and Planetary Laboratory**

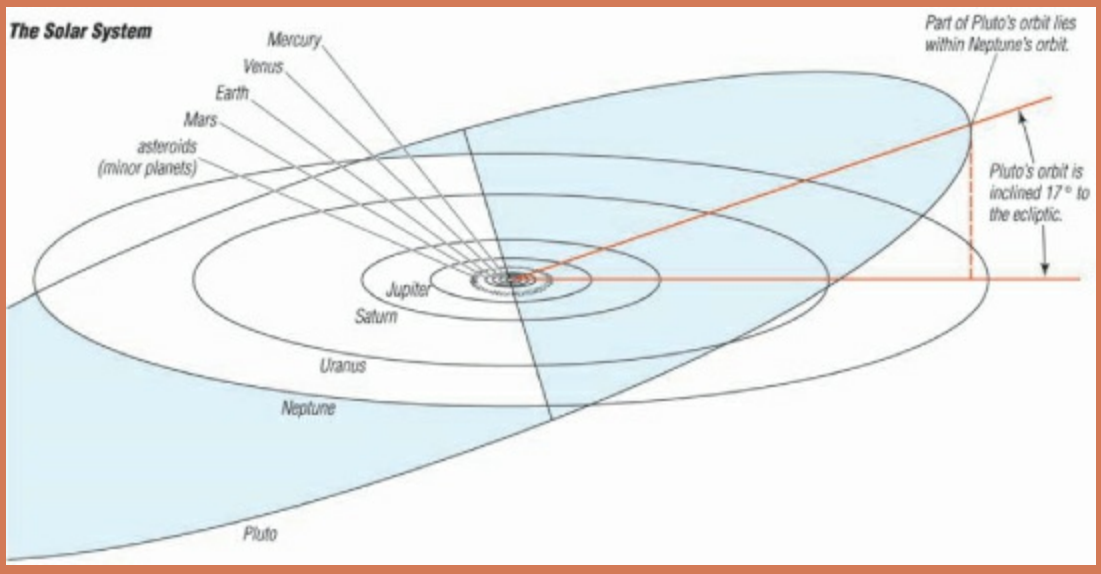
Uranus' motion did not follow the exact path predicted by Newton's theory of gravitation. This problem was happily resolved by the discovery of an eighth planet, which was named Neptune. Two mathematicians, John Couch Adams and Urbain-Jean-Joseph Le Verrier, had calculated Neptune's probable location, but it was the German astronomer Johann Gottfried Galle who located the planet, in 1846.

Even then some small deviations seemed to remain in the orbits of both planets. This led to the search for yet another planet, based on calculations made by the U.S. astronomer Percival Lowell. In 1930 the U.S. astronomer Clyde W. Tombaugh discovered the object that became known as Pluto.

Pluto is an icy body that is smaller than Earth's Moon. The mass of Pluto has proved so small—about $^{1}/_{500}$ of Earth's mass—that it could not have been responsible for the deviations in the observed paths of Uranus and Neptune. The orbital deviations, however, had been predicted on the basis of the best estimates of the planets' mass available at that time. When astronomers recalculated using more accurate measurements taken by NASA's *Voyager 2* spacecraft in 1989, the deviations "disappeared."

Orbits of the Planets

All eight planets travel around the Sun in elliptical orbits that are close to being circles. Mercury has the most eccentric (least circular) orbit. All the planets travel in one direction around the Sun, the same direction in which the Sun rotates. Furthermore, all the planetary orbits lie in very nearly the same plane. Mercury's is the most tilted, being inclined about 7 degrees relative to the plane of Earth's orbit (the ecliptic plane).



Shown are orbits of the eight planets and the dwarf planet Pluto. Pluto's orbit is tilted about 17 degrees relative to the ecliptic, or the plane of Earth's orbit. Pluto's orbit is also much more elliptical than are the orbits of the planets.

Encyclopædia Britannica, Inc.

Except for Venus and Uranus, each planet rotates on its axis in a west-to-east motion. In most cases the spin axis is nearly at a right angle to the plane of the planet's orbit. Uranus, however, is tilted so that its spin axis lies almost in its plane of orbit.

For some 75 years astronomers considered Pluto to be the solar system's ninth planet. This tiny distant body was found to be unusual for a planet, however, in its orbit, composition, size, and other properties. In the late 20th century astronomers discovered a group of numerous small icy bodies that orbit the Sun from beyond Neptune in a nearly flat ring called the Kuiper belt. Many of Pluto's characteristics seem similar to those of Kuiper belt objects. Several of those objects are roughly the same size as Pluto, and one, named Eris, is known to be larger. In 2006 the International Astronomical Union, the organization that approves the names of celestial objects, removed Pluto from the list of planets. Instead, it made Pluto the prototype of a new category of objects, called dwarf planets. Pluto is also considered one of the larger members of the Kuiper belt.

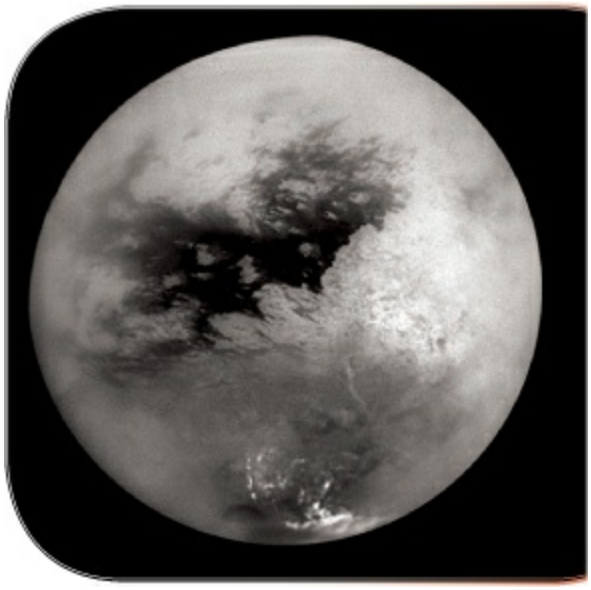
The planets can be divided into two groups. The inner planets—Mercury, Venus, Earth, and Mars—lie between the Sun and the asteroid belt. They are dense, rocky, and small. Since Earth is a typical inner planet, this group is sometimes called the terrestrial, or Earth-like, planets.

The outer planets—Jupiter, Saturn, Uranus, and Neptune—lie beyond the asteroid belt. They are also called the Jovian, or Jupiter-like, planets. These are much larger and more massive than the inner planets. Jupiter has 318 times Earth's mass and in fact is more massive than all the other planets combined. Being made mostly of hydrogen and helium (mainly in liquid forms), the Jovian planets are also much less dense than the inner planets.

NATURAL SATELLITES

Six of the planets—Earth, Mars, Jupiter, Saturn, Uranus, and Neptune—are known to have satellites. Dwarf planets and asteroids can also have moons. Because the Moon is large in comparison with Earth, the Earth-Moon system

is sometimes called a double planet. Pluto's large satellite, Charon, has just over half the diameter of Pluto, and the two are often considered a double-body system. Although several other satellites are much larger than either Earth's Moon or Charon, these other satellites are much tinier, by comparison, than the bodies they circle.

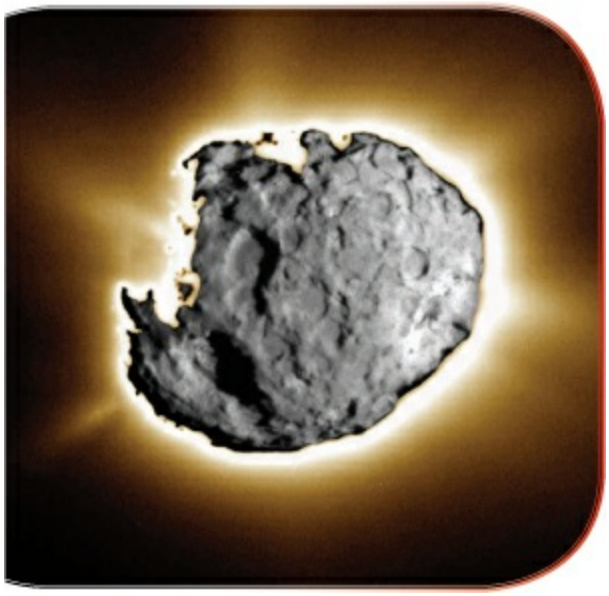


***Saturn's moon Titan appears in a mosaic of nine images taken by the* Cassini *spacecraft and processed to reduce the veiling effects of the moon's atmosphere. The continent-sized region Xanadu Regio shows as the large bright patch on the right, while bright methane clouds appear near Titan's south pole.* NASA/JPL/Space Science Institute**

Many of the natural satellites are fascinating worlds in their own right. Jupiter's moon Io has numerous active volcanoes spewing sulfur compounds across its surface. Europa, Jupiter's next moon out, may well have a vast ocean of liquid water underneath its icy crust. Neptune's Triton has mysterious geysers erupting in spite of frigid surface temperatures near − 400 °F (− 240 °C).

Also of great interest are Saturn's moons, especially Titan and Enceladus. Titan, its largest moon, has a thick, cold, hazy atmosphere of nitrogen and methane. On its surface, drainage channels—apparently carved by showers of

methane rain—cut through a crust of water ice and empty into flat areas, which may be dune fields, methane mudflats, or perhaps even liquid methane lakes. Although Enceladus is small and very cold, it is geologically active, with geysers near the south pole that spout water vapor and water ice.



***The* Stardust *spacecraft took this composite image of Comet Wild 2's nucleus during a flyby in 2004. It combines a short-exposure image that resolved surface detail and a long-exposure image that captured jets of gas and dust streaming away into space*. NASA/JPL-Caltech**

ASTEROIDS AND COMETS

On January 1, 1801, the Italian astronomer Giuseppi Piazzi found a small planetlike object in the large gap between the orbits of Mars and Jupiter. This rocky object, later named Ceres, was the first and largest of thousands of asteroids, or minor planets, that have been discovered. (Ceres is now also considered a dwarf planet.) While most asteroids are found in a belt between Mars and Jupiter, there are a few others. Some cross Earth's orbit and may present the threat of a rare collision with Earth at some time in the future.

Comets are among the most unusual and unpredictable objects in the solar system. They are small bodies composed mostly of frozen water and gases,

with some silicate grit. This composition and the nature of their orbits suggest that comets were formed before or at about the same time as the rest of the solar system.

Comets apparently originate beyond the orbit of Neptune. At such distances from the Sun, they maintain very low temperatures, preserving their frozen state. They become easily visible from Earth only if they pass close to the Sun. As a comet approaches the Sun, some of its ices evaporate. The solar wind pushes these evaporated gases away from the head of the comet and away from the Sun. This temporarily gives the comet one or more long, glowing tails that point away from the Sun.

Determining the source of comets has been a puzzle for astronomers. Some comets return to the inner solar system periodically, traveling in long, elliptical orbits that may reach from Earth's orbit to beyond Neptune. Halley's comet, for example, appears about every 76 years. Comets lose material with each pass near the Sun, however, and can probably survive only a few hundred such visits before their volatile materials are exhausted. This means that they could have traveled on such orbits for only a small fraction of the solar system's widely accepted 4.6-billion-year history.

Other comets' orbits have been traced out to tens of thousands of astronomical units and have periods of millions of years. Some of these comets may in fact be making their first ever visits to the inner solar system. Such considerations led Jan Oort in 1950 to suggest the existence of a vast, spherical cloud, containing perhaps billions of comets. Disturbances such as the gravitational influence of passing stars could deflect these comets toward the Sun.

Gerard P. Kuiper proposed in 1951 that another group of icy bodies, including dormant comets, might exist in a belt just outside Neptune's orbit. Discoveries starting in the 1990s have confirmed Kuiper's hypothesis, as hundreds of objects have been found at about the distance he predicted. The belt is thought to contain many millions of icy objects, most of them small. However, the largest Kuiper belt objects, including Eris and Pluto, are massive enough to also be considered dwarf planets.

Current thinking suggests that many of the short-period comets, or those that complete an orbit in less than 200 years, may have originated in the Kuiper belt. They were perhaps directed into the inner solar system by collisions with each other and gravitational encounters with Neptune. Long-

period comets are thought to originate in the Oort cloud (whose existence is considered highly probable, but not proven). The cloud may have been produced long ago, as icy bodies near and inside Neptune's orbit were thrown far out from the Sun by gravitational encounters with the outer planets.

DOES LIFE EXIST ELSEWHERE?

Life as we know it, particularly in its higher forms, can exist only under certain chemical and physical conditions. The requirements for life are not fully known, but they almost surely include a reasonable temperature range, so that chemical bonding can occur, and a source of energy, such as sunlight or heat coming from the interior of a planet. It has also been commonly assumed that solvents like water and some protection from ultraviolet radiation are needed. A number of environments within the solar system may meet these criteria. For example, organisms could exist in the subsurface permafrost of Mars or in an ocean under the icy crust of Jupiter's moon Europa. Some comets and asteroids contain organic matter (meaning carbon-based molecules, not necessarily resulting from life). This suggests that the basic ingredients for life are common in the solar system.

Mars is an intriguing place to look for life. Spacecraft have photographed large features that appear to be dry riverbeds. Data from NASA's *Spirit* and *Opportunity* rovers in the early 2000s strongly suggest that liquid water once existed on the planet's surface. Also, data from the European Mars Express orbiter and from Earth-based telescopes suggest that methane is being released from beneath the surface, and a possible source for this could be subsurface colonies of bacteria.

In 1976 the Viking landers looked for evidence of life in the Martian soil. They found no organic molecules. However, a couple of Viking experiments that looked for signs of metabolic processes (i.e; processes that show life), yielded seemingly positive results. These findings have been widely (but inconclusively) interpreted as a result of strange chemical reactions rather than life. While life has not been found on Mars, many scientists think that it may have existed in a wetter past.

Discoveries of life existing in extreme or unusual environments on Earth —such as in hot bedrock miles beneath the surface and in colonies near volcanic vents on the deep sea floor—have widened prospects for finding life

elsewhere. No place in the solar system other than Earth, however, is easily suitable for human colonization or for large land plants or animals. It is possible that other stars may be orbited by more Earthlike planets. In fact, the number of such worlds in the universe may be truly enormous. However, the only place life has been found so far is on Earth. One example is very little to go on, especially if we are part of the example. With little information regarding the likelihood of life arising in other places, even under Earth-like conditions, discussion of life elsewhere remains speculative.

Chapter 4
THE UNIVERSE

Cosmology is the scientific inquiry into the nature, history, development, and fate of the universe. By making assumptions that are not contradicted by the behavior of the observable universe, scientists build models, or theories, that attempt to describe the universe as a whole, including its origin and its future. They use each model until something is found that contradicts it. Then the model must be modified or discarded.

A REVOLUTION IN COSMOLOGY

In 1905 Albert Einstein published his theory of special relativity, which showed that space and time can be seen as aspects of a deeper structure, space-time, and that mass and energy are really the same thing. In 1916 he followed this with his theory of general relativity, in which gravity is understood as a warping, or bending, of space-time by the presence of mass. This new theory of gravity, which has passed a number of experimental tests, paved the way for the modern scientific study of cosmology.

Einstein soon realized that his basic equations, in their simplest form, required that the universe be either expanding or contracting. Its matter—along with space itself—would be either flying apart or falling together. Einstein, like most astronomers at the time and much like Newton two centuries before, objected to such a conclusion. He favored instead the idea of a static universe, one essentially unchanging through infinite time. He realized that his equations could include a special term, called the "cosmological constant", which could supply a sort of repulsive force, capable of balancing gravity and keeping the universe static. While it might be simpler to leave it out (by assigning it a value of zero), Einstein assigned it a positive value so that the universe would be essentially unchanging, as he expected.

THE EXPANDING UNIVERSE

In 1929, however, U.S. astronomer Edwin Hubble announced an amazing discovery—evidence that the universe actually is expanding. In the mid-1920s astronomers had found that a class of cloudlike objects, then called spiral nebulae, are actually huge, distant groups of billions of stars, now called galaxies. Hubble's analysis of their light showed that, with the exception of a few of the closest ones, they are all moving away from Earth, many at tremendous speeds. When Einstein realized that he had held in his hands the monumental prediction of a universe evolving through time and had then undone it with the cosmological constant, he called it the "greatest blunder" of his life.

To determine the distances to other galaxies, Hubble compared the brightness of certain giant stars in these galaxies to the brightness of presumably similar stars in our own galaxy, whose distances had been

calculated by a number of other, overlapping methods. To determine the speed at which a galaxy was receding from Earth, he observed its spectrum. Dark lines in the spectrum of colors can be identified as being produced by specific elements known on Earth. For these galaxies, the lines were shifted away from their normal wavelengths toward the red, long-wavelength part of the spectrum.

This effect is known as redshift. It is similar to the Doppler effect for sound, in which, for instance, a train whistle's pitch seems to drop as the train passes by. The sound waves from the receding train whistle are stretched out behind the train and arrive at the listener with a longer wavelength and thus a lower pitch. The wavelengths of light from a receding object are likewise stretched longer, making the light appear redder than it would otherwise. (If a galaxy were moving closer, it would appear to be blue instead of red).

Hubble plotted recessional speeds of galaxies versus their distance from Earth and found that the more distant ones were moving away at proportionally greater speeds, so that the graph formed nearly a straight line. This relation is known as Hubble's law. It can be written $v = H \times d$, where v is the velocity of recession, d is the distance to the galaxy, and H is the slope of the line and is called the Hubble constant. According to this, for example, a galaxy twice as far away from an observer as another galaxy is moving away from the observer twice as fast.

It is important to realize that this expansion is not best thought of as galaxies rushing away from each other through preexisting space, but rather as an expansion of space itself, which "carries" the galaxies with it. With this in mind, the redshift can be considered as the effect of space having stretched since the light was emitted. Light emitted when the universe was half its current size, for example, would now be seen to have twice the original wavelength.

***This composite photo reveals the deepest view of the visible universe ever seen. Created by the space-bound Hubble Telescope, it reveals galaxies from the time shortly after the big bang*. NASA/Getty Images**

The Uniform Universe

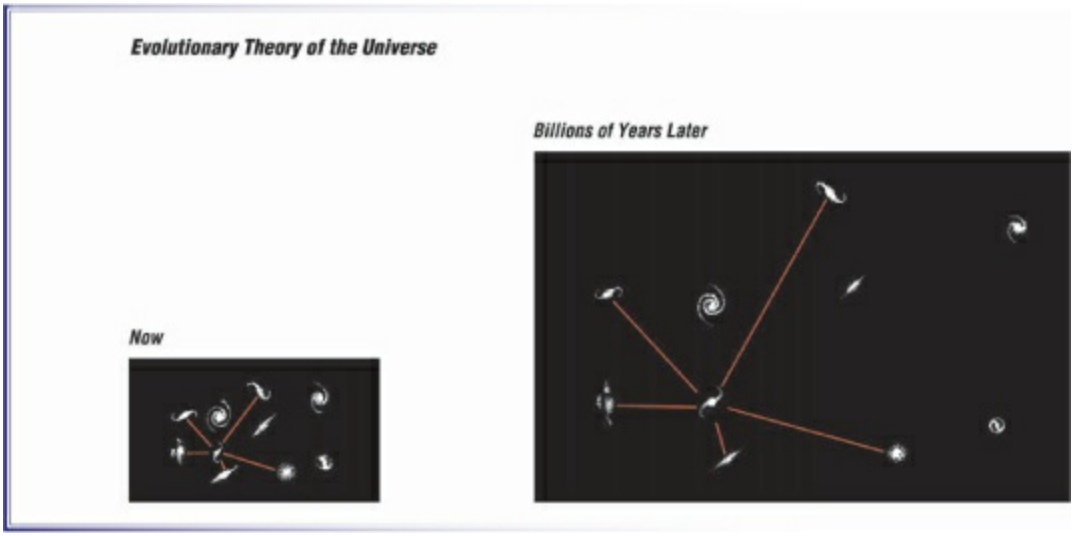
The distribution of the galaxies Hubble studied also provided evidence of the cosmological principle—two important properties that the universe is assumed to have. At large scales the universe is isotropic, or looks about the same in all directions, and homogeneous, or is about the same everywhere. If the positions of vast numbers of galaxies were plotted to form a map of the observable universe, their large-scale distribution would look roughly the same from all angles and in all regions.

This means that, even though we see other galaxies rushing away from us, we cannot claim to be located in the "center"; an observer anywhere in the universe would see about the same thing. Every cluster of galaxies, including ours, is receding from all others as space expands.

THE BIG BANG

Hubble's findings about the expansion of the universe have a very interesting implication. If the motion of the galaxies is traced back in time, it implies that they were once all in the same place—"here." The universe would have then been greatly compressed and therefore very dense and hot. This scenario—of a universe that "exploded" out of an extremely tiny, dense, and hot initial state—became known as the big bang theory. In the 1920s Georges Lemaître and Aleksandr Friedmann proposed early versions of such a model, which George Gamow and other cosmologists modified in the 1940s.

Tracing the expansion of the universe back toward its presumed origin can be thought of as like playing a movie backward. As one "rewinds," one finds the universe's average temperature increasing, much like that of a gas being compressed. At an age of a few hundred thousand years, the temperature would have been thousands of degrees Fahrenheit or Celsius, thus stripping atoms of their electrons. If one could have witnessed this state, there would have been a brilliant glow coming from all directions. Calculations show that at about a second after the beginning, temperatures would have been billions of degrees. Under such conditions the nuclei of atoms would be smashed apart into their constituent neutrons and protons. At even earlier times, neutrons and protons would be broken up into the quarks of which they are made. These would be embedded in a soup of radiation—mainly gamma rays—along with electrons and positrons.



***According to the evolutionary, or big bang, theory of the universe, the universe is expanding while the total energy and matter it contains remain constant. Therefore, as the universe expands, the density of its energy and matter must become progressively thinner. At left is a two-dimensional representation of the universe as it appears now, with galaxies occupying a typical section of space. At right, billions of years later the same amount of matter will fill a larger volume of space*. Encyclopædia Britannica, Inc.**

Predictions of the Big Bang Theory

Two crucial predictions emerge from this scenario. Playing the movie forward again, one finds that in the rapidly cooling universe, only a fraction of the protons and neutrons would have had time to fuse together to form elements heavier than hydrogen, which has only one proton. Calculations show that, by the time this fusion ended about a few minutes after the beginning, the cooling gas would have consisted of nearly 75 percent hydrogen, about 25 percent helium, and trace amounts of deuterium and lithium. One would expect this primordial 3:1 hydrogen-to-helium ratio to dominate the universe even today.

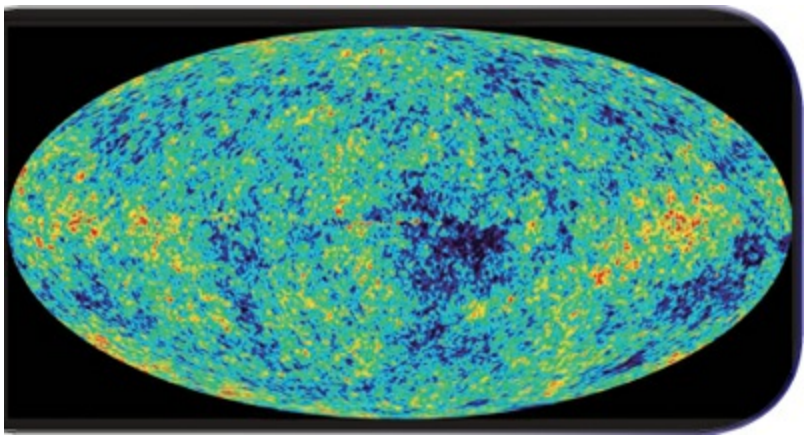
The second prediction involves the light produced by the radiant heat of the early universe. Before the formation of atoms, the particles of light, called photons, frequently scattered off of electrons, which were not yet incorporated into atoms. As atoms formed about 400,000 years after the beginning, the light finally had a clear path. Light that was thus released at a great distance should just now be reaching us. It would be coming from parts of the universe receding from us at nearly the speed of light, so that it would be greatly redshifted, all the way into the microwave region of the spectrum. This microwave glow should be coming from all directions in the sky, with almost uniform intensity.

Evidence for the Big Bang Theory

The first of these predictions was quickly supported by spectroscopic studies. Indeed, the visible matter in the universe does appear to be mostly hydrogen and helium, in about a 3:1 ratio, with only small amounts of heavier

elements. However, the existence of most elements heavier than helium, such as what the Earth—and people—are made of, required an explanation. This was soon accounted for by studies of fusion reactions that power the stars. Stars produce heavier elements in their cores, and some of these stars explode or otherwise expel matter, enriching the universe with a fairly small but significant amount of matter heavier than helium.

Interestingly, the term "big bang" was originally intended as a derisive one; it was coined in the 1940s by Fred Hoyle, who championed a competing model known as the steady state theory. In that model, the universe is expanding, but its general appearance and composition remain constant through time, as new matter is gradually created to fill in the gaps left by matter that has spread out. The universe would be infinitely old and would last forever. For a decade or so, mainly in the 1950s, this theory enjoyed significant support.



This image, showing the first all-sky microwave image of the universe soon after the big bang, was released by a team of astronomers from NASA and Princeton University in 2003. **Getty Images**

COSMIC BACKGROUND EXPLORER (COBE)

In 1964 Arno Penzias and Robert Wilson, working together at Bell Laboratories in New Jersey, discovered the presence of microwave radiation that seemed to permeate the cosmos uniformly. Now

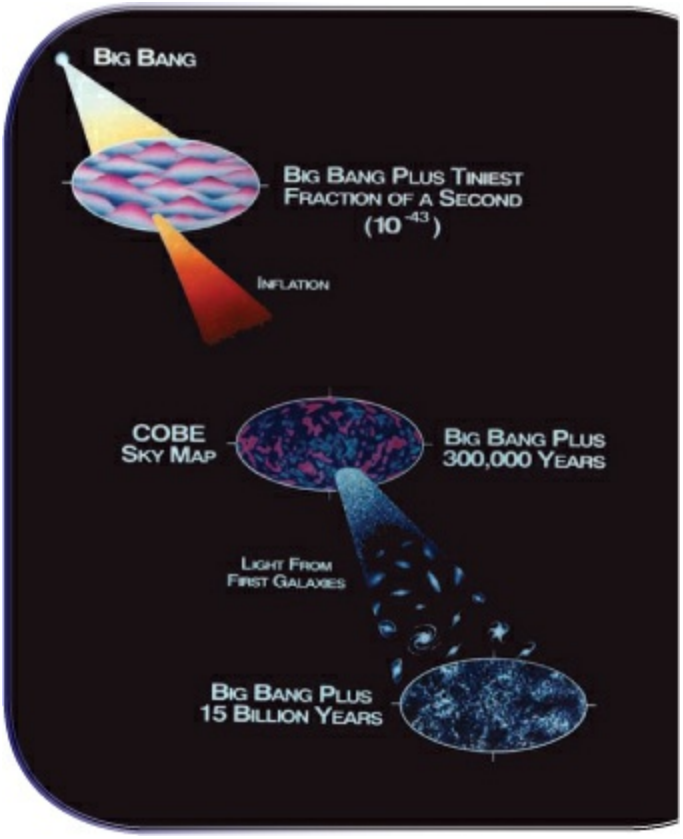
known as the cosmic background radiation, this uniform field provided spectacular support for the big bang model, which held that the early universe was very hot and the subsequent expansion of the universe would redshift the thermal radiation of the early universe to much longer wavelengths corresponding to much cooler thermal radiation. Penzias and Wilson shared a Nobel Prize for Physics in 1978 for their discovery, but, in order to test the theory of the early history of the universe, cosmologists needed to know whether the radiation field was isotropic (that is, the same in every direction) or anisotropic (that is, having spatial variation).

***The Cosmic Background Explorer*. Photo courtesy of Smoot Group/George Smoot**

The COBE satellite was launched by NASA on a Delta rocket on November 18, 1989, to make these fundamental observations. COBE's Far Infrared Absolute Spectrophotometer was able to measure the spectrum of the radiation field 100 times more accurately than had previously been possible using balloon-borne detectors in Earth's atmosphere, and in so doing it confirmed that the spectrum of the radiation precisely matched what had been predicted by the theory. The Differential Microwave Radiometer produced an all-sky survey that showed "wrinkles" indicating that

the field was isotropic to 1 part in 100,000. Although this may seem minor, the fact that the big bang gave rise to a universe that was slightly denser in some places than in others would have stimulated gravitational separation and, ultimately, the formation of galaxies. COBE's Diffuse Infrared Background Experiment measured radiation from the formation of the earliest galaxies. After four years of observations, the COBE mission was ended, but the satellite remained in orbit.

Discoveries in the 1960s, however, weighed heavily against the steady state theory. Especially groundbreaking was evidence in 1965 to support the other crucial prediction of the big bang theory: a nearly uniform glow of microwaves is indeed coming from every direction in the sky. Eventually satellite observations, including those from the Cosmic Background Explorer launched in 1989, showed that the spectrum of this radiation was of the type known as a blackbody spectrum, which is the kind expected to result from a hot, glowing gas such as that of the early universe. Furthermore, its wavelength (about .39 inch [1 centimeter], which corresponds to a temperature of only about 3° Kelvin) matched closely calculations of just how redshifted this light should be now. This "wall of light," called the cosmic background radiation, is exactly what the big bang model predicts, so the theory gained very wide acceptance.



***Artist's concept depicting crucial periods in development of the universe after the big bang*. Time & Life Pictures/Getty Images**

Chapter 5
THE HISTORY OF ASTRONOMY

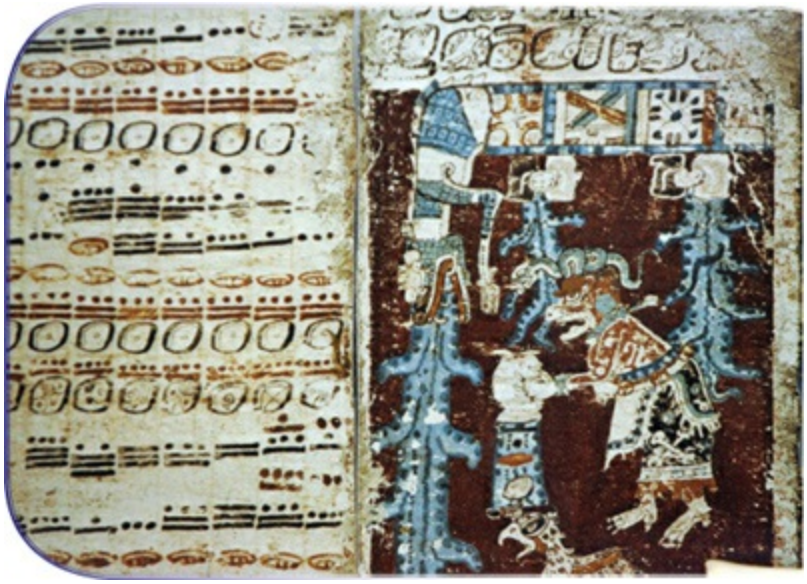
Until the invention of the telescope and the discovery of the laws of motion and gravity in the 17th century, astronomy was primarily concerned with noting and predicting the positions of the Sun, Moon, and planets. The catalog of objects studied today is much broader, as the development of modern instruments and the advent of scientific space probes have allowed astronomers to investigate the reaches of space far beyond Earth's

atmosphere.

ANCIENT OBSERVATIONS

The ruins of many ancient structures indicate that their builders observed the motions of the Sun, Moon, and other celestial bodies. The most famous of these is probably England's Stonehenge, which was built between about 3100 and 1550 BC. Some of the monument's large stones were aligned in relationship to the position of the rising Sun on the summer solstice. Several hundreds of other ancient structures showing astronomical alignment also have been found in Europe, Egypt, and the Americas.

In many early civilizations, astronomy was sufficiently advanced that reliable calendars had been developed. In ancient Egypt, astronomer-priests were responsible for anticipating the season of the annual flooding of the Nile River. The Maya, who lived in what is now central Mexico, developed a complicated calendar system about 2,000 years ago. The Dresden Codex, a Mayan text from the 1st millennium AD, contains exceptionally accurate astronomical calculations, including tables predicting eclipses and the movements of Venus.



A copy of part of the Dresden Codex is shown in Guatemala City, Guatemala. **Orlando Sierra/AFP/Getty Images**

In China, a calendar had been developed by the 14th century BC. In about 350 BC a Chinese astronomer, Shih Shen, drew up what may be the earliest star catalog, listing about 800 stars. Chinese records mention comets, meteors, large sunspots, and novas.

The early Greek astronomers knew many of the geometric relationships of the heavenly bodies. Some, including Aristotle, thought Earth was a sphere. Eratosthenes, born in about 276 BC, demonstrated its circumference. Hipparchus, who lived around 140 BC, was a prolific and talented astronomer. Among many other accomplishments, he classified stars according to apparent brightness, estimated the size and distance of the Moon, found a way to predict eclipses, and calculated the length of the year to within 6 ½ minutes.

The most influential ancient astronomer historically was Ptolemy (Claudius Ptolemaeus) of Alexandria, who lived in about AD 140. His geometric scheme predicted the motions of the planets. In his view, Earth occupied the center of the universe. His theory approximating the true motions of the celestial bodies was held steadfastly until the end of the Middle Ages.

***Ptolemy of Alexandria*. SSPL via Getty Images**

FOUNDATIONS OF MODERN ASTRONOMY

In medieval times Western astronomy did not progress. During those centuries Hindu and Arab astronomers kept the science alive. The records of the Arab astronomers and their translations of Greek astronomical treatises were the foundation of the later upsurge in Western astronomy.

In 1543, the year the astronomer Nicolaus Copernicus died, came the publication of his theory that Earth and the other planets revolved around the Sun. His suggestion contradicted all the authorities of the time and caused great controversy. The Italian astronomer Galileo supported Copernicus' theory with his observations that other celestial bodies, the satellites of

Jupiter, clearly did not circle Earth.

***Nicolaus Copernicus*. Fotosearch/Archive Photos/Getty Images**

The astronomer Tycho Brahe rejected Copernicus' theory. Yet his data on planetary positions were later used to support that theory. When Tycho died, his assistant, Johannes Kepler, analyzed Tycho's data and developed the laws of planetary motion. In 1687 Newton's law of gravitation and laws of motion explained Kepler's laws.

Meanwhile, the instruments available to astronomers were growing more sophisticated. Beginning with Galileo, the telescope was used to reveal many

hitherto invisible phenomena, such as the revolution of satellites about other planets.

The development of the spectroscope in the early 1800s was a major step forward in the development of astronomical instruments. Later, photography became an invaluable aid to astronomers. They could study photographs at leisure and make microscopic measurements on them. Even more recent instrumental developments—including radar, telescopes that detect electromagnetic radiation other than visible light, and space probes and manned spaceflights—have helped answer old questions and have opened astronomers' eyes to new problems.

NICOLAUS COPERNICUS

The Polish astronomer Nicolaus Copernicus is often considered the founder of modern astronomy. His study led to his theory that the Earth rotates on its axis and that the Earth and the other planets revolve around the Sun.

Copernicus was born on February 19, 1473, in Toruń, the son of a merchant. The boy was reared by his uncle, a wealthy Catholic bishop, who sent him to the University of Kraków to study mathematics. Copernicus also studied law at Bologna and medicine at Padua in Italy. In 1500 he lectured on astronomy in Rome. He returned to his uncle's castle near Frauenburg in 1507 as attending physician to the old man. Copernicus spent much time studying the stars.

The Copernican theory was contrary to the Ptolemaic theory then generally accepted. In 1530 he finished his great book, O*n the Revolutions of the Celestial Spheres*. His theory was in opposition to the teachings of the Roman Catholic church, and the book was not published for 13 years. Copernicus apparently received the first copy as he was dying, on May 24, 1543. The book opened the way to a truly scientific approach to astronomy.

THE IMPACT OF ASTRONOMY

No area of science is totally self-contained. Discoveries in one area find applications in others, often unpredictably. Various notable examples of this involve astronomical studies. Newton's laws of motion and gravity emerged from the analysis of planetary and lunar orbits. Observations during a solar eclipse in 1919 provided dramatic confirmation of Albert Einstein's general theory of relativity. The behavior of nuclear matter is now better understood because of studies of neutron stars—a special kind of star that can form when giant stars collapse. And some elementary particles are now better understood as a result of measurements of the abundance of helium in the universe.

Astronomical knowledge also has had a broad impact beyond science. The earliest calendars were based on astronomical observations of the cycles of repeated solar and lunar positions. Also, for centuries, familiarity with the positions and apparent motions of the stars through the seasons enabled sea voyagers to navigate with moderate accuracy. Perhaps the single greatest effect that astronomical studies have had on modern society has been in molding its perceptions and opinions. Our conceptions of the cosmos and our place in it, our perceptions of space and time, and the development of the systematic pursuit of knowledge known as the scientific method have been profoundly influenced by astronomical observations. In addition, the power of science to provide the basis for accurate predictions of such phenomena as eclipses and the positions of the planets and, later, of comets has shaped an attitude toward science that remains an important social force today.

Chapter 6
AMATEUR ASTRONOMY

Amateur astronomy is a popular pastime around the world. Astronomy enthusiasts usually subscribe to popular astronomical periodicals and often own moderately priced telescopes. Almost every large city has some kind of astronomy club, and many countries have national organizations of amateur astronomers interested in promoting their hobby.

As amateurs far outnumber professional astronomers, it is often an

amateur astronomer who discovers a new comet or an exploding star. Professional astronomers usually concentrate their research efforts on one type of object or may not observe the sky at all. A beginning backyard star-gazer, scanning the nighttime sky for pure enjoyment, may see such an object before anyone else.

Dedicated amateur astronomers observe the sky on a regular basis and take advantage of the vast store of information recorded by others. Numerous star charts and catalogs in books and software and on Web sites give the positions of objects and predictions for celestial events. Other guides describe equipment to use and observational techniques. Many advanced amateurs record data using home computers, light-sensitive electronic equipment, and special photographic emulsions like those of professionals.

USING THE UNAIDED EYE

A simple joy of amateur astronomy is learning to identify the brighter stars and constellations. These mark the time of night and the season, and their positions in the sky also depend on the observer's location. Knowledge of the distances and natures of stars can add to one's appreciation of the night sky.

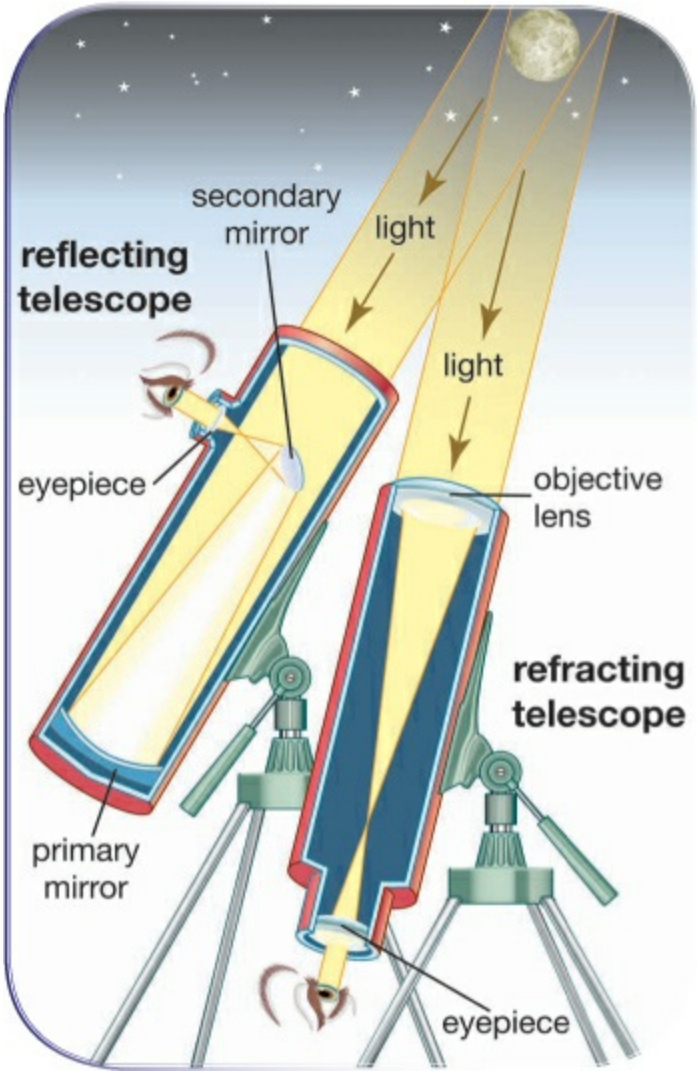
Some important observations can be made with very little equipment. Observing displays of auroras and meteor showers, for example, requires only the unaided eye. All one needs is a good clear horizon and dark skies away from city lights and pollution. It is also simple to photograph auroral displays and, with some luck, to photograph a meteor trail with high-speed film or digital media in a stationary camera on a tripod.

USING TELESCOPES

The two most important aspects of a telescope are light-gathering power and magnification. The larger the area of the light-collecting lens or mirror (called the objective) of a telescope, the more light it gathers, so that fainter objects can be seen. A larger objective also provides finer detail in an image, permitting use of higher magnification (which makes the image larger). With binoculars or a small telescope, a person can easily observe many celestial objects not visible to the unaided eye. The Sun, Moon, planets, and so-called deep-sky objects—nebulae, star clusters, and galaxies—can all be seen with

simple instruments.

Observers with such instruments can count sunspots and measure their size and location. Since the Sun is so bright, the telescope's main lens or mirror can be quite small. To avoid severe eye damage, one must never look directly at the Sun with unaided eyes or with a telescope without a proper Sun filter, including during an eclipse (unless the Sun's disk is totally covered). During eclipses people may be tempted to look at the Sun when it is partly blocked, but even a very small part of the Sun's surface remaining visible can damage the retina and cause a permanent blind spot in the eye.



Amateur astronomers use two main types of telescopes: reflecting and refracting. A reflecting telescope uses mirrors to

***focus light from a distant object, while a refracting telescope uses a lens to do so. Both types have a lens in the eyepiece to magnify the image formed*. Encyclopædia Britannica, Inc.**

A good way to view the Sun is by projecting its image through a telescope eyepiece onto a screen or white cardboard. Another way is to use a Sun filter. One type covers the entrance of the telescope with thin layers of shiny aluminum. This material reflects most sunlight, letting only a safe amount through. The more expensive hydrogen-alpha filter is sometimes included as an integral part of a small telescope. These filters allow exciting, real-time observation of many details of the Sun's surface, including flamelike prominences, which appear and dissipate in a matter of hours.

The Moon is a fascinating object to study with a telescope. Even a magnification of less than 50 power will show numerous craters, mountains, and dark lunar "seas." The best place to observe is along the line created by the border between the dark and light portions of the Moon, where sunlight highlights higher elevations. Lunar eclipses are always safe to view because moonlight is much less intense than sunlight.

***People point toward Mars as a boy focuses a telescope at Nehru Planetarium in New Delhi, India, in 2003*. Prakash Singh/AFP/Getty Images**

Planets are best viewed with a telescope of 100 to 300 power. These

higher magnifications generally require an objective lens or mirror 3 inches (76 millimeters) or more in diameter to maintain adequate brightness and detail. Good and often moderately priced telescopes of this size can easily show features such as Saturn's rings, Jupiter's cloud belts and large moons, and Mars's polar ice caps. Some amateur astronomers use color filters to increase the contrast of planetary features by subtracting some colors of light from the image. A yellow or blue filter, for example, might highlight patterns in Jupiter's clouds, while a red filter might enhance the dark areas on the surface of Mars.

Light Pollution

A common problem faced by amateur astronomers is light pollution. Near large cities, artificial lighting makes the night sky so bright that only a few stars can be seen with the naked eye and faint objects are difficult to see even with large telescopes. Special telescope filters can block much of the artificial light while letting through most light from some types of astronomical objects (such as nebulae). Many people travel far up into the mountains or other remote areas to find truly dark skies. There are also efforts, especially by the International Dark-Sky Association, to get cities to adopt less offensive and more efficient lighting. In places where such actions have been taken, more stars are now visible, allowing people a better view of the beauty of the night sky.

Lights from the Aberthaw Power Station light up the night sky on November 16, 2009, near Barry, Wales, United Kingdom, spreading light pollution. **Matt Cardy/Getty Images**

Earth's atmosphere begins to blur the image at magnifications above 300 power, even in larger telescopes. To view faint objects, such as star clusters, nebulae, and galaxies, a larger telescope may be needed. Amateurs often own telescopes 8 inches (203 millimeters) or more in diameter. While most of these are commercially produced, some amateurs make their own telescopes —usually of the reflecting type—even grinding and polishing the mirrors by hand. With care and patience, many people make telescopes of higher quality than most store-bought ones, some as large as 20 inches (508 millimeters) in diameter.

An Explosion of New Technology

Since the late 20th century new products have revolutionized amateur astronomy. One such item is the GOTO (for "go to") computerized (and usually motorized) telescope mount. In the past, one often had to consult detailed star charts to find faint objects. Developing skill at finding distant galaxies and nebulae is a worthy pursuit, but many beginning hobbyists had difficulty finding anything besides the Moon and a few bright planets or stars. The GOTO mounts allow users to align the telescope using as few as two bright stars. They then simply use a keypad to get directions to—or to have a motorized mount turn the telescope to—any of thousands of objects in the computer's database. Motorized mounts can also follow objects so they stay in view as the Earth turns. Such technology spares many beginners the frustration that might otherwise lead them to abandon the hobby.

Also available are fairly inexpensive still and video cameras with charge-coupled devices (CCDs), very sensitive equipment that captures images electronically. These can be attached to telescopes and the output stored electronically or sent to a television or computer screen. Computer image-

processing programs allow one to combine hundreds of images to produce views of planets and deep-sky objects rivaling or even surpassing those produced at large observatories only a few decades ago. Even a modest-sized telescope in a suburban area can provide a view on a monitor surpassing that seen directly through a much larger telescope under dark skies.

A wide range of “planetarium”-type computer programs are also available. With databases of millions of stars and other objects, they allow accurate and highly detailed simulations of the sky as seen from anywhere on Earth—at present or even thousands of years in the future or past. Not only do these programs give enthusiasts a way to pursue their hobby on cloudy nights, but some of them can even remotely control a telescope.

SERIOUS AMATEUR ASTRONOMY

Astronomy is perhaps the only science in which nonprofessionals can readily make real and valuable contributions. While most amateurs pursue the hobby primarily for enjoyment, some use their equipment and expertise to do significant research, often contributing data to professionals through a number of organizations.

Many amateur groups study the thousands of known variable stars in the Milky Way galaxy. These stars vary in brightness over a period of several days or weeks as they swell and contract. Members of the American Association of Variable Star Observers have made millions of observations of variable-star fluctuations. This organization prepares charts of variable-star fields and light curves of major variable stars and is a source of much information that is nearly impossible to obtain elsewhere. Most European countries and many other nations also have well-organized variable-star observation groups.

This bright Leonid fireball is shown during the storm of 1966 in the sky above Wrightwood, California. The Leonid Meteor Shower occurs every year in mid-November. **NASA/Getty Images**

An amateur astronomer with a good telescope can also observe an event called an occultation. As the Moon, a planet, or even an asteroid moves through space, it sometimes passes in front of a star. For a short time the star will appear to “blink out” to people at a particular location on Earth. If the time of this event is noted accurately and the observer’s position is known, it is possible to determine very accurately the speed and position of the moving object. The time it takes for the star to reappear is also noted, and, if information can be gathered from several observers, it may be possible to determine the diameter of the body passing in front of the star. A group called the International Occultation Timing Association was formed to gather such data.

Other serious amateurs focus their attention on objects in the solar system. The members of the Association of Lunar and Planetary Observers, for example, make careful sketches of and capture photographic or other images of features of the Sun, Moon, and planets and track the motions of faint objects orbiting the Sun.

Much knowledge of meteor showers comes from groups such as the International Meteor Organization and the American Meteor Society, whose members spend thousands of hours recording the times and locations of individual meteors. From this information, they calculate an average hourly rate as well as the radiant, or origin, of the meteor stream. Most annual meteor showers are associated with old comets that have left a trail of dust in space. Normally an observer will see 20 to 50 meteors an hour during a meteor shower, but occasionally a spectacular shower of many thousands of "shooting stars" will reward the meteor watcher.

All the groups mentioned, as well as local planetariums, can help beginning amateurs learn more about their specialty. Two periodicals published in the United States are also useful to both beginning and advanced amateur astronomers: *Sky and Telescope* and *Astronomy*.

CONCLUSION

Huge advances in our understanding of the universe have come in recent years, but many questions remain. Will the big bang scenario continue to account for new data gathered on the universe's structure? Does life exist elsewhere in the universe than on planet Earth—or has it ever existed beyond Earth in the past? Will scientists be able to more thoroughly describe the universe at its earliest instants? What caused the universe to come into existence in the first place, and are there other such universes? Some of these questions may never be answered with certainty, but astronomers and

cosmologists will continue to seek answers. If history is any indicator, surprises may well await us.

GLOSSARY

annular eclipse An eclipse in which a thin outer ring of the Sun's disk is not covered by the smaller dark disk of the Moon.

asteroid Any of the small rocky celestial bodies found especially between the orbits of Mars and Jupiter.

celestial Of or relating to the sky or visible heavens.

corona A usually colored circle often seen around and close to a luminous body (as the Sun or Moon) caused by diffraction produced by suspended droplets or "occasionally" particles of dust.

dwarf planet A celestial body that orbits the Sun and has a spherical shape but is not large enough to disturb other objects from its orbit.

eclipse The total or partial obscuring of one celestial body by another.

electromagnetic spectrum The entire range of wavelengths or frequencies of electromagnetic radiation extending from gamma rays to the longest radio waves and including visible light.

gamma ray A photon emitted spontaneously by a radioactive substance.

meteoroid A meteor particle itself without relation to the phenomena it produces when entering the Earth's atmosphere.

nebula Any of numerous clouds of gas or dust in interstellar space.

penumbra A space of partial illumination (as in an eclipse) between the perfect shadow on all sides and the full light.

phase A particular appearance or state in a regularly recurring cycle of changes.

refract To deflect from a straight path a light ray or energy wave passing obliquely from one medium (as air) into another (as glass) in which its velocity is different.

satellite A celestial body orbiting another of larger size.

solstice Either of the two points on the ecliptic at which its distance from the celestial equator is greatest and which is reached by the Sun each year on about June 22 and December 22.

spectrograph An instrument for dispersing radiation (as electromagnetic radiation or sound waves) into a spectrum and recording or mapping that spectrum.

totality The phase of an eclipse during which it is total—the state of total eclipse.

umbra A shaded area.

wavelength The distance in the line of advance of a wave from any one point to the next point of corresponding phase.

FOR MORE INFORMATION

Adler Planetarium
1300 South Lake Shore Drive
Chicago, IL 60605
(312) 922-7287
Web site: http://www.adlerplanetarium.org

Founded in 1903, the Adler was America's first planetarium. Its museum has three theaters, space exhibits, and an antique astronomical instrument collection.

Amateur Astronomers Association of New York
P.O. Box 150253
Brooklyn, NY 11215
(212) 535-2922
Web site: http://www.aaa.org

This is an organization helping amateur astronomers to appreciate the night sky and to learn what's new in astronomy.

Hayden Planetarium
Central Park West at 79th Street
New York, NY 10024
(212) 769-5100
Web site: http://www.haydenplanetarium.org

The planetarium operates out of the American Museum of Natural History and features exhibits and online resources.

H.R. MacMillan Space Centre
1100 Chestnut Street.
Vancouver, BC V6J 3J9
Canada
(604) 738-7827
info@spacecentre.ca

The H.R. MacMillan Centre inspires interest in the universe through programming, exhibits, and activities.

Royal Astronomical Society of Canada
203 - 4920 Dundas Street W
Toronto, ON M9A1B7
Canada
888-924-7272
Web site: http://www.rasc.ca

The society offers publications, student resources, and programs throughout Canada.

WEB SITES

Due to the changing nature of Internet links, Rosen Educational Services has developed an online list of Web sites related to the subject of this book. This site is updated regularly. Please use this link to access the list:

http://www.rosenlinks.com/tss/astro

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